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The Second Generation Model:
Future Directions for Model Development

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Fawcett and Sands (2005) and Sands and Fawcett (2005) describe the Second Generation Model (SGM) as of October 2005. Those dates are important because the SGM, like most modeling frameworks, continues to develop and evolve. Next steps in model development will take cognizance of Environmental Protection Agency (EPA) Science Advisory Board (SAB) consultation. Below we discuss a few of the areas where further development is being considered and explored. We divide the discussion into three pieces: 1. Model Enhancements, 2. Behavioral Parameters and 3. Data.

I. Model Enhancements

Six changes in model structure are under serious consideration:

1. Utility function-based household sector. *The current ad hoc set of demand equations employed for the household sector would be replaced with a set of demand equations derived from a utility function. This change would allow the calculation of economic costs in terms of welfare.*
2. International trade. *The present SGM is closed with regard to international trade in only one commodity, carbon permits. This approach is clearly inadequate to understanding the implications of international climate policies. We are therefore working to close SGM markets in all internationally traded commodities.*
3. Nested production function. *The SGM presently employs a CES production and dual cost function to represent the relationship between inputs and outputs in producing sectors of the economy. The CES function has the desirable property that it is well behaved over a wide range of parameters. It has the disadvantage that it is not a second-order approximation to any arbitrary production function at a point. We propose to replace the simple CES production function with a Generalized CES function.*
4. Zero-profit condition on all new investment. *We propose to make the zero-profit condition on all new investment the standard investment implementation in the SGM.*
5. Endogenous non-CO_2 greenhouse gas emissions *Given the importance of non-CO_2 greenhouse gases to the climate problem, we plan to explore the option of modeling non-CO_2 GHG emissions as a fully endogenous behavior.*
6. Computational environment. *The present version of the model is coded in Fortran. We intend to explore an object-oriented computational environment.*

We discuss each below.

I.1 Household Sector

We recognize the importance of being able to provide a utility function based estimate of the welfare impacts of potential climate policies. The present consumer demand system in SGM does not provide such a capability; consisting as it does of a set of equations that are a constant times price and income, with exponents on the price and income terms which represent elasticities. Consistency of expenditures with total consumption is ensured through a scaling factor applied to all demand equations. While these equations were not derived from a utility function, we have determined the constraints on demand system parameters needed to satisfy the theoretical properties of a well-behaved demand system. It turns out that these constraints allow the same number of degrees of freedom in setting elasticities as the Linear Expenditure System. We plan to explore the feasibility of constructing a household sector based on a utility function yielding both a Linear Expenditure System as well as the empirical characteristics necessary to allow for the changes in the structure of consumption we believe will occur over the time frames and changes in per capita income relevant to the climate problem[1].

I.2 Trade

The present implementation of the global version of the SGM allows equilibrium-based trade only in carbon permits, with other trade levels for sectors either being exogenously set or allowed to vary as each domestic economy responds to a fixed world price. Individual SGM regions can be thought of as a small open economy, where some goods are traded and some are not, and each region faces an exogenous balance of payments constraint. We recognize that a number of climate issues require a stronger trade capability if issues such as the relocation of industry or the impact of large scale permit revenues are to be adequately addressed, with different options required for the regional and global versions. We are considering several possibilities for expanding the trade capability of the SGM. Our approach is to first survey alternatives presently used by other modelers as given in Table 1.

[1] Not all goods in the SGM are unambiguously superior. Some goods, for example, grains, exhibit a pattern of consumption that changes with income per capita. At low levels of per capita income, for example grain consumption rises as income increases. However, at some per capita income level direct consumption of grains reaches a peak and subsequent increases in income can actually cause consumption to decline. The ability to provide a representation of utility consistent with such Engles curves is an important consideration in the redesign of the household sector.

Table 1. Alternative Approaches to International Trade

Approach	Characteristics
HOS (Heckscher, Ohlin, Samuelson)	For each tradable good, domestic economy faces exogenous price determined by world market or regional trading block.
Armington (full bilateral trade)	Domestic consumption of each good is a CES composite of domestic production and an Armington composite of imports. Each bilateral trade relationship represents a unique product with a unique price.
Armington (no bilateral trade)	Domestic consumption of each good is a CES composite of domestic production and an Armington composite of imports. Imports are not differentiated by country of origin.
Logit allocation	Preserves quantity and energy balance. Domestic consumption of each good is a logit share composite of domestic production and an import good.

Given the emphasis we have placed on consistent physical measurement of energy flows in the SGM, we have a concern about the Armington trade specification especially with respect to goods that are relatively homogeneous such as crude oil and natural gas since it does not preserve energy balance. If the imported good is crude oil, measured in energy units, then the energy content of the Armington composite is not equal to the sum of the energy in the crude oil components of the Armington composite. A possible option would be to use a logit allocation option as proposed by the Asian Integrated Modeling (AIM) group in Japan as a way to preserve quantity balance. We will explore options to allow for both maintaining energy balances and imperfect substitution between imported and domestic goods.

I.3 Nested CES Production Function

All production functions in SGM are of the CES functional form with a single nest, which implies that the same elasticity of substitution applies to any pair of inputs. Conceptually, it makes sense to extend production functions in SGM to two or more nests, allowing increased flexibility in the production structure. We will consider the implementation of a generalized nested CES functional structure in the SGM[2].

The implementation of a nested CES structure can be used to preserve some of the attractive behavioral properties of the CES function. As we extend the production structure to multiple nesting levels, we will need to address the following: What nesting

[2] A generalized nested CES has the form $Y=G(g_1, g_2, \dots, g_N)$, where $g_i=F(x_1, x_2, \dots, x_N)$, where x_i is an input to the production process, Y is the output, F is a function with CES form, and G is a function with CES form. This production function was first explored by Edmonds and Reister (1982) and more recently by Perroni and Rutherford (1995, 1998). It has been shown that the generalized nested CES function is a second order approximation to any production function, satisfying certain regularity conditions, at a point.

structure is appropriate for each production sector? Can we develop a process for determining substitution elasticities which uses the limited available empirical support and provides reasonable simulation properties?

I.4 Zero Profits Condition Investment Option

A CGE model must solve for a core set of unknowns, and these are listed in the first column of Table 2. We require the same number of equations as unknowns, and the other columns compare the equations used by SGM to those found in a typical CGE model. The main difference between the system equations in SGM and that of a typical CGE model is the investment structure. In a typical CGE model the zero-profit conditions determine investment across producing sectors; the SGM uses an explicit investment function for each producing sector. In addition, the SGM assumes that current period investment is part of the current period productive capital stock, which is derived by interpolating by investment in the previous period (five years prior) and current investment levels.

Table 2. Single-Region System Equations

Unknowns	SGM Equations	Typical CGE Equations
Prices of nontradables	Market clearing	Market clearing
Rentals of primary factors	Market clearing	Market clearing
Allocation of capital across production sectors (for constant-returns-to-scale production)	Investment function (investment in each producing sector is a function of the rate of return, but rates of return are not equalized across producing sectors)	Zero-profits conditions (capital is allocated across producing sectors to equalize rates of return)
Household, government expenditure	Determined with a specific sequence of calculations (investment, production, government revenue, government transers, household income)	Income balance
Price of domestic emissions allowances	Market clearing	Market clearing

Presently, the SGM has two options for allocating capital to producing sectors, the investment accelerator and the output accelerator. We are adding a third investment option, one that enforces the zero-profit condition. In the case of SGM, the zero-profit condition is equivalent to stating that the expected profit rate equals one, or that a new investment just breaks even. For production sectors that use this third investment option, the investment accelerator or output accelerator functions would no longer be used. This option would then allow SGM to solve for the set of core unknowns in the same way as a typical CGE model.

There may be cases where we want the capability for specific investment rules for particular sectors, say electricity generation in developing countries. Therefore, we will retain several investment options and the options may vary across producing sectors.

I.5 Endogenous Non-CO_2 Greenhouse Gas Emissions

Currently, CO_2 emissions abatement is endogenously determined in the model, but non-CO_2 emissions abatement comes from an exogenous marginal abatement cost curve. The major problem with the current implementation is that the cost associated with achieving any level of non-CO_2 emissions abatement is not accounted for in the model, thus the full range of general equilibrium effects associated with non-CO_2 emissions abatement are not realized.

Accordingly, a high priority for future model development is to incorporate non-CO_2 emissions abatement into the production structure of the model, so that their costs are fully accounted for. Given the range of sources and technologies involved in managing non-CO2 emissions, as well as the relatively small size of each emission source, it is unlikely that we will implement a process fully parallel to the CO_2 control process. Rather we will seek an intermediate strategy, such as integrating under the marginal abatement cost curve to get total cost of control and then allocating that control cost in a manner similar to the way in which investment demands are treated. Such an approach would allow us to capture the costs and impacts on expected profits without having to dramatically increase the complexity of the model. In addition, we want to revisit the mapping between non-CO_2 emissions sources and sectors of the model to ensure that all sources are associated with the most appropriate sector and/or to consider whether additional sectors might be warranted.

I.6 Model Implementation

The theoretical structure of SGM is independent of any particular computing environment. However, the choice of computing environment matters, especially in terms of the resources needed to modify and extend source code, the ease of moving data into the model, transparency of the source code, availability of solvers, and licensing requirements of the development environment.

SGM was originally coded in Fortran 77 in 1991. However, adding new model features became increasingly difficult and it became clear by the late 1990s that the SGM would need to be converted to a computing environment that was more modular, allowing members of a development team to work on individual components of the model. Two development paths were explored: using the object-oriented features of Fortran 90 to create a modular version of SGM in Fortran 90; and a complete re-write of the code in an object-oriented language such as C++ or Java.

In 2002, a Fortran 90 version of SGM was written to determine the extent that Fortran 90 can support modular programming and to test new model features including: (1) unlimited number of vintages of the capital stock; (2) consumer demand based on the Linear Expenditure System; (3) use of zero-profit conditions to allocate capital across producing sectors; and (4) introduction of carbon dioxide capture and storage technologies into electricity generation. This transitional version of SGM is limited to single-region operation, but it demonstrates the ease that model structure can be changed in a modular or object-oriented computing environment. This version of SGM is used as a research tool, but it also supports specialized studies for the Energy Modeling Forum and analysis of greenhouse gas mitigation options in Japan and Germany.

Current model development efforts are focused on building a fully object-oriented version of SGM that captures everything we have learned so far in previous implementations, exploits XML as a standard for transferring data into SGM, and allows shared code between SGM and MinCAM, a partial-equilibrium energy-economy model used at PNNL. The new object-oriented version of SGM is being coded primarily in C++, although some of the data manipulation code and user interface are written in Java.

We recognize that the majority of other teams developing top-down economic models for climate policy analysis use GAMS as the development environment. One advantage of GAMS is the availability of a wide range of solvers, especially the mixed complementarity solvers that automatically handle cases where constraints, such as an emissions limit, may or may not be binding. One disadvantage is that its cost may restrict the number of institutions that we could collaborate with outside the United States. However, the primary restriction is the long held view that the results of our modeling work should be available to all potential users without the need to acquire proprietary tools. While the SGM has not been widely distributed to the user community, in excess of a thousand copies of the predecessor to the MiniCAM, the Edmonds-Reilly model, have been distributed.

II. Behavioral parameters

We recognize the importance of improving the logic behind the parameter values used in the SGM. We use the term logic, as the choice of appropriate values for a behavioral parameter has a variety of constraints, none of which is *a priori* most important. First, the parameters need to be based on the best available empirical estimates. Second, the parameters need to provide appropriate model behavior when, for example, relative prices are well outside historical ranges. Third, the long time frame of the model can allow the violation of physical constraints on energy conversion efficiencies. Fourth, we have certain empirical regularities, such as capital-output ratios, that either need to hold or have a convincing explanation as to why the behavior has changed.

In order to improve the empirical basis of the model parameters, we plan to use a graduate student to develop an enhanced literature basis for our choice of model parameter values. We will also develop a formal sensitivity process to explore the impacts of different parameter values and parameterizations. This framework will also assist with other aspects of model validation.

III. Improved benchmark data

Data always has problems and the bigger the scope of the model the wider the range of potential problems. There is obvious room to improve the data used for the SGM, both to make it more current and to improve the inputs for those regions where we have not implemented a full set of benchmark data. In addition, the anticipated extended trade capability will require an additional data effort. As we consider how to move to a more current, more complete set of data inputs, the same concerns about physical consistency and regional variation in model structure that have driven the SGM process so far will continue to be relevant.

As described in some detail in the forthcoming GTAP data discussion document, we anticipate continuing to use our current data methodology for those regions where we have existing collaborations. In regions where we do not have an extant active collaboration, we will most likely move to using GTAP data along with IEA data as the benchmark data, but apply our procedure rather than just accept the GTAP procedures. This will ensure consistency as well as allow us to resolve judgment issues in the light of our modeling goals, rather than just accepting the GTAP goals and their rules for implementing them. (There are always inconsistencies in data sets constructed from multiple sources and judgment is always required in resolving these inconsistencies).

As noted in Sands and Fawcett (2005), we developed the methodology for combining information from economic input-output tables and energy balances to provide a physically consistent representation of energy flows in a CGE model. These methods were developed independently of, and possibly prior to, efforts by the Global Trade Analysis Project (GTAP) to produce the GTAP-E data set. Rutherford and Paltsev (2000) provide an alternative method for combining economic data with energy balances. This procedure also starts with aggregated IEA energy balances, but preserves energy quantities. The authors refer to this data set as GTAP-EG. Therefore, while there is general agreement on the need to use energy balances in constructing a benchmark data set, multiple methods are available. We are in the process of evaluating both the GTAP-E and GTAP-EG procedures but are inclined (subject to finding no compelling reason to change after we complete our review) to remain with our current process given our favorable experience with it.

The most important data item on our calendar is to update and improve the benchmark data sets used as inputs to the development of model inputs. For this we will need to develop a more automated process for combining economic and energy data sets as well as to understand the issues that may arise in developing a consistent global data when we use both data sets derived from our regional collaborators as well as GTAP based data sets.

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